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A method for assessing measurement precision and stability of optical probes

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Abstract
The current strategy for measuring non-specular metre-scale surfaces – for instance segmented freeform optics post-grinding – in the mid- to low-spatial frequency bandwidths (S-filter), involves the use of contact probe based systems where measurement precision is a limiting factor. Equivalent non-contact optical probes claim accuracies up to an order of magnitude higher and could therefore improve current measurement systems. Chromatic confocal probes measure the distance to a surface using the principle of axial chromatic dispersion. The stability of a CHRocodile SE 300 µm probe was shown to be 200 ± 20 nm over an eight hour measurement period. A probe holder should be designed with a low thermal expansion material in order to thermally insulate the probe measurement for further investigation. The accuracy of the probe was assessed at the extremes of its measurement range. The maximum deviation over a 5 µm displacement was measured to be 85 nm. The entire measuring range should be investigated.

Keywords: Metrology, Non-specular surfaces, Non-contact probing, Long term stability

1. Introduction

Non-contact optical probes, such as chromatic probes, have potential to replace contact probes for some applications [1]. The use of non-contact probes in existing contact probe based systems could decrease measurement time and uncertainty [1]. Some optical probing techniques are capable of measuring non-specular metre-scale surfaces – for instance segmented freeform optics post-grinding – in the mid- to low-spatial frequency bandwidths (S-filter). Current measurement techniques use contact probe based systems where measurement precision is a limiting factor. State-of-the-art contact probes have a measurement uncertainty of 0.25 µm (2σ) [2] due to errors including: the probe-surface interface position, flexibility in the probe, and thermal expansion of the probe. Equivalent non-contact optical probes claim accuracies up to an order of magnitude higher [3]; employing these probes could therefore improve current measurement systems.

In this paper, two methods are presented: the first assesses the long term stability of a probe; whilst the second investigates the accuracy of a probe. These techniques contribute to the assessment of the viability of using chromatic probes in the measurement of large non-specular surfaces.

2. Measurement principle

A chromatic confocal probe measures the distance to a surface using the principle of axial chromatic dispersion within a single point optical sensor [1, 4]. Figure 1 shows how an axial chromatic dispersion lens can be used to split the constituent wavelengths of white light, thus realising spectral encoding. Each wavelength of the light is focused at a different point along the axis of the lens corresponding to a point within the measuring range: the difference between the focal distance of the largest and the focal distance of the smallest wavelengths.

When an object is positioned within the measuring range, light is reflected back to the probe. The light that is focused at the specific position of the objects surface is reflected with the highest intensity. An optical fibre is utilised as a pin hole so only light focused at its core is transmitted to the detector and the probe-fibre pair behaves as a confocal microscope [1, 4].

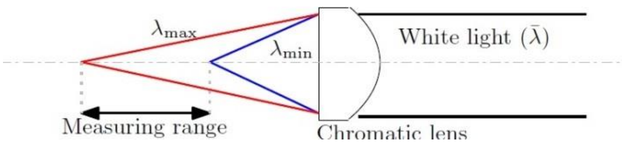

Figure 1. A white light source with wavelength range, $\bar{\lambda}$, is directed into a chromatic lens and dispersed axially to generate a unique focal point for each wavelength [1, 4].

The transmitted light is directed onto a detector for spectral decoding. The detector is a spectrometer type CCD. Given that the light reflected back up the fibre by the object surface consists of only a single wavelength, the spectrometer can be used to analyse and identify the wavelength; thus, the position of the measured surfaces is decoded [1, 4].

2.1. Error classification

All probes have an associated measurement uncertainty caused by errors in the measurement systems. A probe's purpose is to allow the recoding of a position on a surface relative to a given reference frame. Error caused by the probe-surface interaction can be categorised into four types [5]: geometric, kinematic, stiffness, and thermal.

Nouira *et al.* present a method for the characterisation of error sources of chromatic probes [6]. This method uses a metrology frame CMM and a laser interferometer to analyse the effect of measurand: colour, material, roughness, axial and radial motion, tilt angle, and changing measurement angle.

3. Stability evaluation test

The time to measure a metre-scale freeform surface is significant. If an optical probe based system is to be used to measure such a surface, the probe's measurement stability should be analysed.

3.1. Method

A CHRocodile SE 300 µm probe was held in a fixed position by an aluminium probe holder with a measurand surface placed within the probe's measurement range. Figure 2 shows the experimental set-up. The artefact was constructed from a machinable ceramic and its surface was non-specular. The measurement of position was recorded over eight hours.

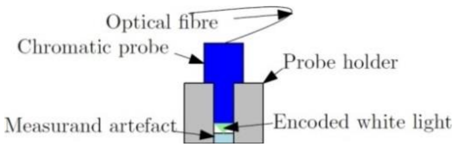

Figure 2. A chromatic probe held by a probe holder to measure a constant distance to the artefact surface.

3.2. Results

Figure 3 shows the position measurement of a CHRocodile SE 300 µm probe. This is shown with the temperature of the probe holder and the air and a fast Fourier transform (FFT) of the position measurement.

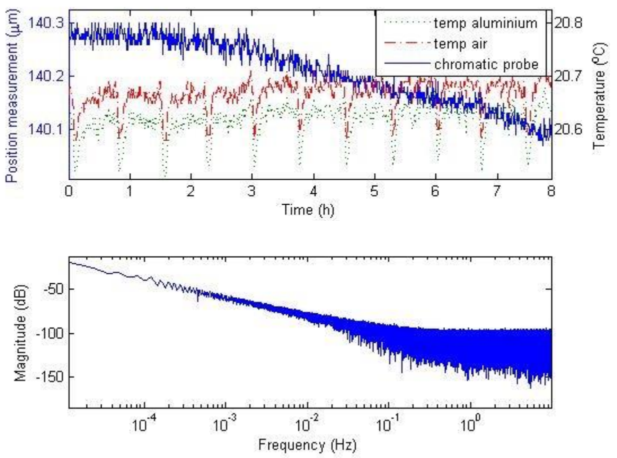

Figure 3. The position measurement of a chromatic probe over an eight hour period, the temperature of an aluminium probe holder, and air temperature (top) and fast Fourier transform of the measured position.

The probe was stable to ± 20 nm during hours one and two; then changed linearly throughout the remaining measurement period by 200 ± 20 nm. The FFT shows low frequency changes in the position measured highlighting measurement instability. Investigation is required to determine the cause of these changes. The temperature increased over this time period. A low thermal expansion holder has been designed with multiple clamping positions to determine a thermally decoupled probe mounting position and thermally insulate the probe.

4. Accuracy testing

In order to validate whether a probe has the capability to measure a metre-scale freeform surface, assessment of the probe's measurement accuracy is required.

4.1. Method

A CHRocodile SE 300 µm probe was held with orientation control and aligned normal the measurand surface. Figure 4 shows the experimental set-up. The probe was incrementally displaced along its measurement axis. Its position measurement was recorded and the deviation from the reference position calculated. The displacement was controlled on a 1D motion axis with < 2.4 nm sub-divisional error [7].

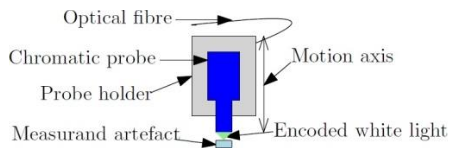

Figure 4. A chromatic probe held by a probe holder with orientation control. The holder is set-up on a precision linear axis.

4.2. Results

Figure 5 shows the difference between displacement measured by the probe and the reference position measured. As the probe was displaced through its measurement range from 10 µm to 15 µm and 290 µm to 285 µm the maximum deviation was 36 ± 4 nm and 85 ± 3 nm respectively.

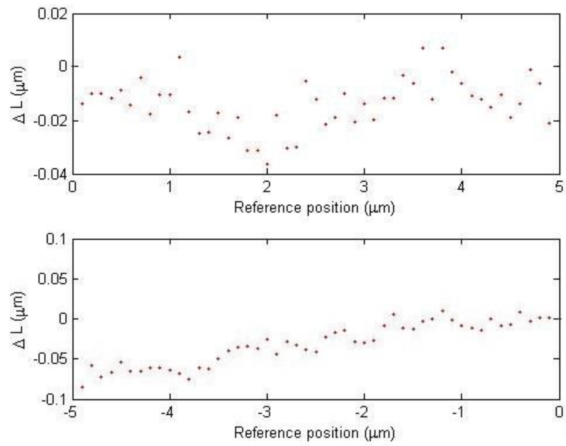

Figure 5. The difference between the displacement measured by a chromatic probe and the reference position as measured by a precision motion system (ΔL), moving from 10 µm to 15 µm (top) and 290 µm to 285 µm (bottom) as measured by the chromatic probe.

5. Conclusion

The stability of a chromatic probe was 200 ± 20 nm over an eight hour measurement period. The stability test should be thermally insulated for further investigation. Maximum deviation over a 5 µm displacement was 85 ± 3 nm. Multiple assessments of the entire measuring range should be undertaken for further accuracy and repeatability testing.

Acknowledgments

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References

[1] Leach R. 2011, *Optical measurement of surface topography*, pages 71-106, Springer.
[2] RENISHAW. 2015, RMP600 high-accuracy touch probe. http://www.renishaw.com/en/rmp600-high-accuracy-touch-probe--8880, accessed: 2016-1.
[3] Precitec Optronik GmbH. 2014, *Optical Sensor CHRocodile SE Operation Manual*.
[4] Perrin H, Sandoz P and Tribillion GM. 1994 Profilometry by spectral encoding of the optical axis. In *Proc. SPIE 2340* , volume 2340, pages 366-374.
[5] Zhongwei Y, Yuping Z, and Shouwei J. 2003, Methodology of NURBS surface fitting based on off-line software compensation for errors of a CMM. *Precision Engineering*, **27(3)**:299-303.
[6] Nouira H, El-Hayek N, Yuan X, and Anwer N. 2014, Characterization of the main error sources of chromatic confocal probe's for dimensional measurement. *Measurement Science and Technology*, **25(4)**:044011.
[7] Moore Nanotechnology Systems, Technical department, Personal communication, 2016-4.

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